MOD RS
SER. 221

INSTRUCTION BOOK

for

MODEL RS

RESOLVER STANDARDS

Gertsch

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FOR

MODEL RS

RESOLVER STANDARDS

1 March 1964

THE SINGER COMPANY • METRICS DIVISION
Gertsch DEPARTMENT
3211 S. LA CIENEGA BLVD., LOS ANGELES, CAL.

Gertsch

GERTSCH PRODUCTS, Inc.

3211 SOUTH LA CIENEGA BOULEVARD, LOS ANGELES 16, CALIFORNIA • UPTON 0-2761 - VERMONT 9-2201

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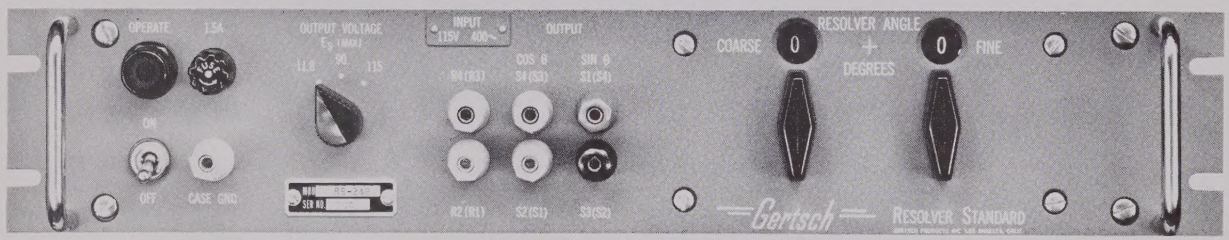


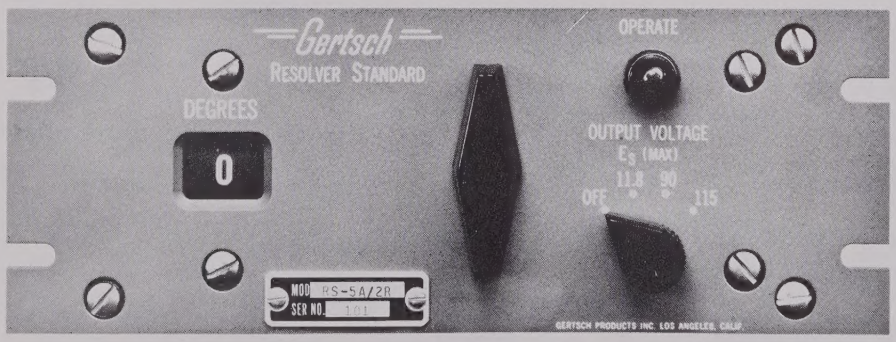


Figure 1-1. Model RS Resolver Standard

SECTION I
GENERAL DESCRIPTION

1-1. PURPOSE.

1-2. Resolver Standards are generally used to transmit precise angular data to Resolver Control Differential Transmitters (RD's) and Resolver Control Transformers (RC's). Most commercially available resolvers of this type may be excited from a Gertsch Resolver Standard without affecting the 2-second accuracy.

1-3. GENERAL DESCRIPTION.

1-4. Gertsch Resolver Standards are precision transformer instruments, designed to simulate the "ideal" electrical outputs (± 2 seconds-of-arc) of a Resolver Control Transmitter (RX). When driven by an external signal source the Resolver Standard generates, in precise angular increments (normally 5°), two isolated voltages. One of the output voltages is directly proportional to the sine of the angle displayed on the dial, and the other is proportional to the cosine. Both outputs are isolated from each other. Quadrant switching is provided to simulate operation over a full 360°.

1-5. Because of their very low output impedance and extremely low output impedance unbalance, Resolver Standards may be operated under normal load with no degradation of accuracy.

1-6. MODELS COVERED.

1-7. All models of the standard function in the same manner, however a variety of models has been designed to cover specific requirements. Refer to the General Specifications for a description of the major model differences.

1-8. Knob control models are completely self-contained units and require no operating power. However, these models use a coarse and fine switch to set the equivalent angular position and the settings of the two switches must be added to obtain the total angle. One-knob models combine the coarse and fine switching into a single control with a direct readout of the angular position.

1-9. Rotary solenoid models include the electrical control circuitry necessary for automatic operation. The units are designed to advance sequentially in 5° increments and may be controlled locally or remotely, A Nixie readout of the angular position is included on the front panel of the unit. 115/230 vac power is required for operation. Normally the units are shipped from the factory wired for 115 vac operation. By simple rearrangement of straps on a terminal board, the unit may be converted for use with 230 vac power.

1-10. Relay models are designed for automatic checkout systems, where programming from punched cards, tape, or remote switches is required. They are particularly suited for applications requiring random access to a discrete group of angles. These units do not include local control facilities or an angular readout. A 28 vdc power source is required for operation of relays.

TABLE I. GENERAL SPECIFICATIONS

*Model No.	Basic Type	Rotor Input Voltage** and Nominal Frequency (VRMS-cps)	Maximum Stator Output Voltage E_S (max) (VRMS)	Frequency Range (cps)†	Max. Effective Output Impedance Unbalance at Nominal Frequency Z_o (unbalance) / sin 2Θ‡ (ohms)	Maximum Typical Load (Z_{SO}) for 2-second Accuracy at Nominal Frequency (ohms)	Remarks
RS-1	Two-Knob	26V-400	11.8V	400-1600	.01 + j.001	100 ∠73°	Economical. Add two dials (coarse & fine) to obtain total angle.
RS-2		115V-400	90V	400-1600	.05 + j.005	500 ∠73°	
RS-2A		115V-400	11.8/90/115V	400-1600	.05 + j.005	500 ∠73°	
RS-2B		115V-400	115V	400-1600	.05 + j.005	500 ∠73°	
RS-4	One-Knob	26V-400	11.8V	400-1600	.01 + j.001	100 ∠73°	Direct readout of angle, selectable with a single knob.
RS-4/2	Half-Rack	26V-400	11.8V	400-1600	.01 + j.001	100 ∠73°	
RS-5	One-Knob	115V-400	90V	400-1600	.05 + j.005	500 ∠73°	
RS-5/2	Half-Rack	115V-400	90V	400-1600	.05 + j.005	500 ∠73°	
RS-5A	One-Knob	115V-400	11.8/90/115V	400-1600	.05 + j.005	500 ∠73°	
RS-5A/2	Half-Rack	115V-400	11.8/90/115V	400-1600	.05 + j.005	500 ∠73°	
RS-5B	One-Knob	115V-400	115V	400-1600	.05 + j.005	500 ∠73°	
RS-5B/2	Half-Rack	115V-400	115V	400-1600	.05 + j.005	500 ∠73°	
RS-7	Rotary Solenoid	26V-400	11.8V	400-1600	.01 + j.001	100 ∠73°	Sequential access. Unit advances 5° per pulse. Direct readout of each angle.
RS-8		115V-400	90V	400-1600	.05 + j.005	500 ∠73°	
RS-8A		115V-400	11.8/90/115V	400-1600	.05 + j.005	500 ∠73°	
RS-8B		115V-400	115V	400-1600	.05 + j.005	500 ∠73°	
RS-10	Relay (programmable)	26V-400	11.8V	400-1600	.01 + j.001	100 ∠73°	Random access. Any multiple of 5° may be selected by energizing 2 or 3 lines.
RS-11		115V-400	90V	400-1600	.05 + j.005	500 ∠73°	
RS-11A		115V-400	11.8/90/115V	400-1600	.05 + j.005	500 ∠73°	
RS-11B		115V-400	115V	400-1600	.05 + j.005	500 ∠73°	

Add R suffix to Model No. when ordering rack mounted units; e.g. RS-5BR.

***Input voltage can be reduced by as much as 1/10.*

†Units may be operated at frequencies lower than the above, by reducing the input voltage in direct proportion.

‡The sin 2θ factor allows △θ to deviate from a pure sinusoidal error curve.

The following specifications apply to all of the Gertsch Resolver Standards listed in the preceding table:

1. *Angular Accuracy*
($Z_{SO} = \infty$; see table for max. load): ±2 seconds-of-arc
2. *Transformation Ratio*, N: $\frac{E_{S\,(max)}}{E_{IN}} \pm .1\%$ max.
3. *Effective Variation in Transformation Ratio (△N) from Nominal, as a Function of Angular Position*: ± .1% max.
4. *Angular Range*: 0-360° continuous
5. *Angular Increments*: 5°
6. *Physical Size and Approximate Shipping Weight*:

Two-Knob
30 lbs, 3½" H x 19" W x 10¼" D* approx.

One-Knob
32 lbs, 3½" H x 19" W x 10¼" D* approx.

Half-Rack
26 lbs, 3½" H x 9½" W x 15½" D* approx.

Rotary Solenoid
38 lbs, 3½" H x 19" W x 14½" D* approx.

Relay (programmable)
36 lbs, 3½" H x 19" W x 15½" D* approx.

Case for 19" W units
5 lbs, 5¼" H x 20" W x 14" D** approx.

* Total mounting depth behind rear panel, including rear terminals and mating connectors where applicable.

** 13" mounting depth behind front panel. Note, rear of case is open to provide access to rear terminals and connectors where applicable.

NBS TRACEABILITY

A certificate is available, on request, showing accuracy measured in terms of a standard which has been certified by the National Bureau of Standards in Washington, D.C.

(NBS Calibration Test 1.6/172436)

SECTION II
INSTALLATION

2-1. KNOB CONTROL MODELS.

2-2. The knob control models only require mounting since no input power is required. All units are designed for standard rack or half rack mounting.

2-3. ROTARY SOLENOID MODELS.

2-4. For local operation, the rotary solenoid units only require mounting and connection to a 115/230 vac, 50 to 400 cps power source. For local operation of the RESET TO 0° control, the mating connector must be installed in the remote control connector. The mating connector is furnished with two jumper wires installed as shown in figure 2-1, Section A.

2-5. For remote operation, the rotary solenoid units require mounting, connection to a 115/230 vac, 50 to 400 cps power source, and wiring of the remote control circuitry. The mating connector for the remote control circuitry is furnished with the unit. Refer to figure 2-1 for the required wiring and control components.

2-6. POWER CONVERSION. Normally, the unit is shipped from the factory wired for operation from a 115 vac power source. To convert the unit for operation from a 230 vac source, proceed as follows:

a. Locate the input power terminal board, located adjacent to the power transformer.

b. Rearrange the shorting straps of the terminal board as shown in figure 2-2.

c. Replace the 3/4 amp power fuse with a 3/8 amp fuse.

2-7. RELAY (PROGRAMMABLE) MODELS.

2-8. Relay models require mounting, connection to the command lines, and connection to a 28 vdc power source. Refer to table 2 for the required command line and power connections. The mating connector for the command control circuitry is furnished with the unit. Each relay requires approximately 140 ma current for operation and selection of an angle requires operation of two or three relays. If the command lines will supply only momentary closures, the latch and delatch lines must be connected. The delatch function requires operation of an additional relay or interruption of the 28 vdc current.

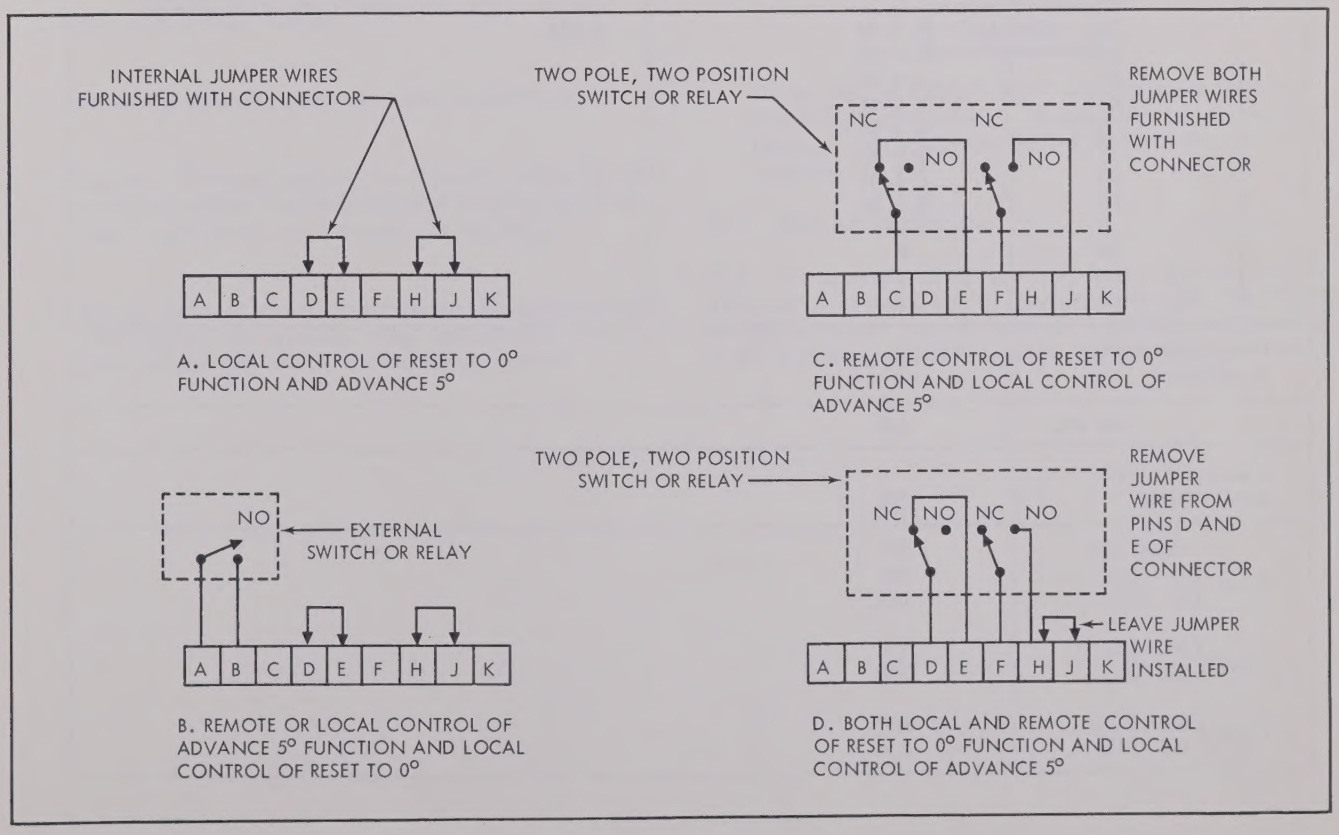

INTERNAL JUMPER WIRES FURNISHED WITH CONNECTOR
A B C D E F H J K
A. LOCAL CONTROL OF RESET TO 0° FUNCTION AND ADVANCE 5°
TWO POLE, TWO POSITION SWITCH OR RELAY
NC NC
NO NO
REMOVE BOTH JUMPER WIRES FURNISHED WITH CONNECTOR
A B C D E F H J K
C. REMOTE CONTROL OF RESET TO 0° FUNCTION AND LOCAL CONTROL OF ADVANCE 5°
NO
EXTERNAL SWITCH OR RELAY
A B C D E F H J K
B. REMOTE OR LOCAL CONTROL OF ADVANCE 5° FUNCTION AND LOCAL CONTROL OF RESET TO 0°
TWO POLE, TWO POSITION SWITCH OR RELAY
NC NO NC NO
REMOVE JUMPER WIRE FROM PINS D AND E OF CONNECTOR
LEAVE JUMPER WIRE INSTALLED
A B C D E F H J K
D. BOTH LOCAL AND REMOTE CONTROL OF RESET TO 0° FUNCTION AND LOCAL CONTROL OF ADVANCE 5°

Figure 2-1. External Wiring of Rotary Solenoid Units

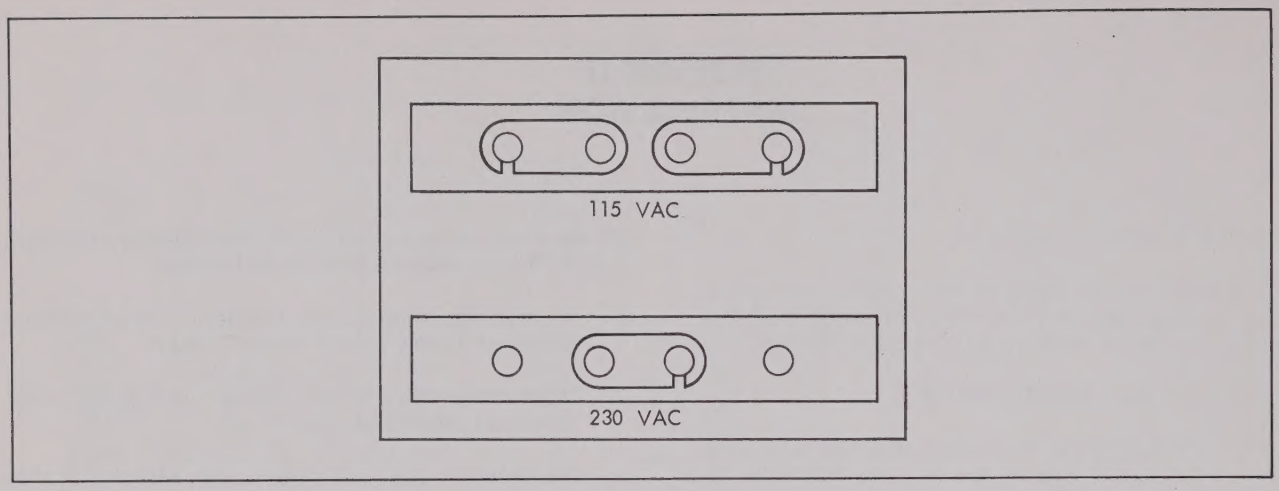


Figure 2-2. VAC Power Connections

TABLE 2. RELAY MODEL CONNECTIONS

Angle (θ)	Pin	(Socket = Winchester #XMRE42PF2016) (Plug = Winchester #XMRE42SC1406)
Fine 0	A	To obtain desired angle, add fine angle to coarse angle and connect specified pins to 0 vdc.
5	B	
10	C	
15	D	
20	E	
25	F	
30	H	
35	J	
40	K	
45	L	
50	K & M	
55	J & M	
60	H & M	
65	F & M	
70	E & M	
75	D & M	
80	C & M	
85	B & M	
Coarse 0	P	
90	R	
180	S	
270	T	
Connect to 0 vdc to delatch	W	
+28 vdc	AA	
Connect to 0 vdc for latching	BB	
Case Gnd	CC	
Sin θ { S1 (S4)	PP	
Sin θ { S3 (S2)	UU	
Cos θ { S4 (S3)	TT	
Cos θ { S2 (S1)	XX	
Input { R4 (R3)	HH	
Input { R2 (R1)	LL	

SECTION III
OPERATING INSTRUCTIONS

3-1. GENERAL.

3-2. Actual operation of the resolver standards is simply a matter of connecting the input and output and selecting the required angle. Precautions to be observed in setting up tests and operating the equipment are listed below. Suggested test setups and applications are given in Appendix II.

3-3. The color coding of the binding posts and the phase relations of the output voltage relative to input voltages conform to the requirements of Military Specification MIL-R-21530D.

3-4. SPECIAL PRECAUTIONS.

3-5. To obtain maximum accuracy, observe the following precautions.

a. Always use high quality switches, with very low contact resistance, whenever it is necessary to switch the outputs.

b. Never fuse the outputs.

c. Do not purposely apply an unbalanced load.

d. Use No. 18 tinned copper wire from the output of the standard to the load and attempt to keep the total lead length from each output pin the same.

e. Stator current should be limited to approximately one ampere for normal relay and switch contact life and should never exceed two amperes.

3-6. ROTARY SOLENOID MODEL.

NOTE

Always wait at least one minute after power is turned on before pressing either the ADVANCE 5° or the RESET TO 0° pushbutton. If either pushbutton is pressed when power is first turned on, the Nixie readout may lose synchronization with the solenoids. To regain synchronization refer to paragraph 5-5.

3-7. To operate a rotary solenoid model, make certain of the following:

a. The unit is connected to a 115/230 vac power source.

b. The power switch is turned on.

c. The REMOTE/LOCAL switch is turned to the applicable position.

d. The mating connector for the remote connector is properly wired (refer to paragraph 2-5) and installed.

CAUTION

Do not use the RESET TO 0° function more than is absolutely necessary. Excessive use of this function will cause excessive wear of the components.

3-8. RELAY MODELS.

3-9. To operate relay models, make certain that 28 vdc power is supplied to the unit and that the power switch is turned on. Selection of angular position can only be accomplished through the remote control circuitry.

SECTION IV
THEORY OF OPERATION

4-1. GENERAL.

4-2. This section includes a general theory of operation for the resolver standards. For a complete analysis, refer to Appendix I.

4-3. GENERAL THEORY.

4-4. The electrical position of a resolver transmitter can be determined from the ratio of the two output voltages to each other. One of the output voltages is proportional to the sine of the rotational angle and the second output voltage is proportional to the cosine. At 0°, the sine output voltage approaches 0. At 45°, the two output voltages are equal and approach a 0.707 ratio to the input voltage.

4-5. In a Gertsch resolver standard, a transformer is placed across the input voltage and functions as a dual voltage divider (see figure 4-1). The two secondaries are tapped to provide the voltage ratios of an ideal resolver. One secondary supplies the voltage which is proportional to the sine of the rotational angle. The other secondary supplies a voltage proportional to the cosine.

4-6. SWITCHING.

4-7. The voltage ratios repeat every 90°; however the mathematical signs of the ratios (+ or -) change for each quadrant. To change signs, the voltages are inverted. Selection of quadrants is accomplished by a coarse switching mechanism. A fine switching mechanism selects the output taps.

4-8. KNOB CONTROL MODELS. Switching is accomplished by two rotary switches: coarse switching by an effectively 4 position switch and fine switching by a 18 position switch. In the two-knob models, each switch is positioned by a separate control. In the one-knob units, a single control accomplishes fine switching directly and coarse switching through a Geneva gear train.

4-9. ROTARY SOLENOID MODELS. (See figure 7-3.) Switching is accomplished by two rotary solenoids: fine switching is accomplished by an 18 position solenoid which is stepped each time voltage is applied and coarse switching is accomplished by an effectively 4 position solenoid which advances one position for each revolution of the fine control switch.

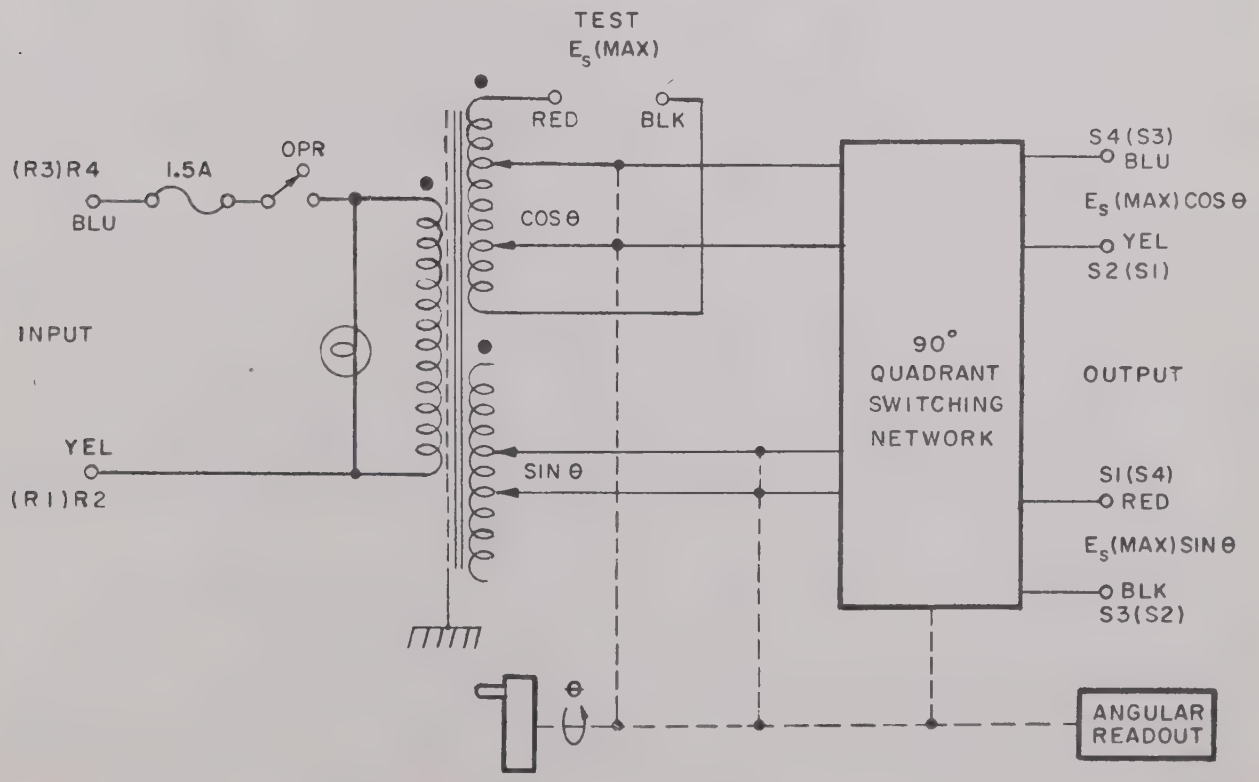


Figure 4-1. Resolver Standard Block Diagram

4-10. Each time current is applied to the coil, the solenoid advances one step forward. When the current source is broken, the solenoid latches into position and is then ready to advance to the next position. The solenoid cannot advance to the next position until the current source is broken.

4-11. When either the local or remote ADVANCE 5° switch is pressed, current is supplied to the fine control solenoid coil as shown in figure 4-2. Energizing current is supplied directly to the solenoid coil through terminals 3 and 4 on the coarse or 4 and 6 on the fine of wafer No. 1 and the self-contained interrupter. As soon as the solenoid steps, the interrupter contacts are broken and remain broken until the solenoid latches. Holding current for the coil is then supplied through the normally closed contacts of the RESET TO ZERO switch S3 and resistor R6. The relay cannot latch until both the local and remote advance switches are released.

4-12. While the fine control solenoid is advanced off from position No. 1, charging current is supplied to capacitors C3 and C4 through contacts of fine control wafer No. 2 (front). When the fine control solenoid advances through all steps and returns to the No. 1 position, capacitors C3 and C4 discharge through the coil of the coarse control solenoid and supply the current required to advance to the next position. When the capacitors discharge or when the fine control solenoid steps off from position No. 1, the coarse solenoid latches into position.

4-13. When the RESET TO 0° switch is pressed, power is supplied to wafer No. 1 of both the coarse and fine control solenoids. The moving contacts of both the wafers are notched to the No. 1 (0°) position. When either solenoid is off the No. 1 position, current is supplied to the coil of the fine control solenoid through its interrupter. Stepping is accomplished by the automatic make and break of the interrupter. When both solenoids return to the No. 1 position, the 0° notches open the coil circuit.

4-14. Angular readout is provided by three Nixie lamps and a commutator assembly. The commutator brush is driven by the fine control solenoid through a 4 to 1 reduction gear train. Operating voltage is applied to all three brushes through one contact of the commutator plate. These three brushes apply power to the applicable members in the Nixie lamps.

4-15. Input ac power is converted to dc power by two separate power supplies. High voltage for the Nixie lamps is supplied by half-wave rectifier CR1 and filtered by capacitor C1 and resistor R2. Low voltage for operation of the solenoids is supplied by a full wave rectifier-filter assembly with resistor R1 acting as a bleeder.

4-16. The unit is converted to 115 vac or 230 vac input power by placement of shorting straps on the input power terminal board. When 115 vac power is used, the dual primaries of the power transformer are placed in

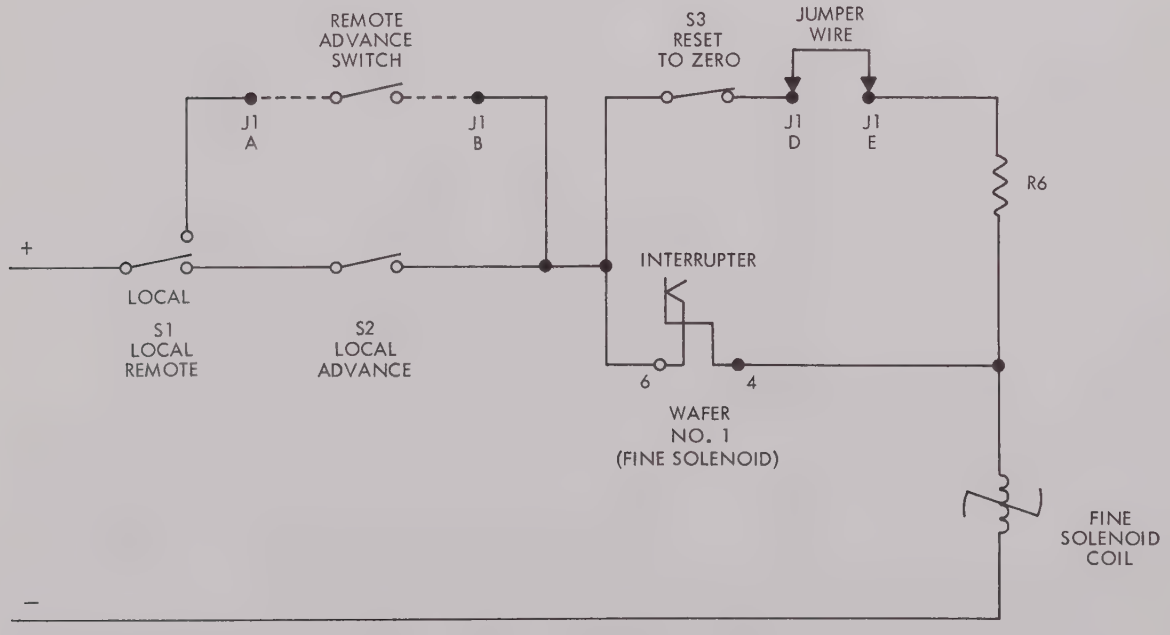


Figure 4-2. Advance 5° Circuit, Rotary Solenoid Model

parallel. When 230 vac power is used, the dual primaries are placed in series. The full secondary output, 230 vac, is supplied to the Nixie lamp power supply and one-half the secondary output, 115 vac, is supplied to the low voltage power supply.

4-17. RELAY MODELS. (See figures 7-4 and 7-5.) Switching is accomplished by 16 relays: 10 relays control fine switching and 5 relays control coarse switching. An additional relay is used to perform a delatch function.

4-18. Relays K1 through K10 select the 0° to 45° tape and each relay is energized by application of ground to a separate pin on the input connector. Relay K11 reverses the output connections for the 50° to 85° coverage. Relays K1 through K10 are interlocked as shown in figure 7-5 so that only one tap can be selected at any one time. The +28 vdc is supplied to the coils through relay contacts. When ground is supplied to two coils at the same time, the contacts of the relay associated with the larger angle break the supply to the relay associated with the smaller angle.

4-19. Relays K12, K13, K14, and K15 control coarse switching and an interlock function.

4-20. If the external control circuitry only furnishes a momentary ground, the hold circuit for the relays is furnished by connecting a ground to pin BB of the input connector. Each relay or set of relays includes a set of hold contacts. Diodes isolate the momentary grounds from the latching ground. If operation from -28V is desired, the polarity of these diodes should be reversed.

4-21. As a result of the interlock system, a relay associated with a small angle can only be energized after a relay associated with a larger angle is released. When the latching ground is supplied, a separate means is required for releasing the larger angle relay. When ground is supplied to pin W of the input connector, relay K16 is energized, the 28 vdc supply line is broken, and all switching relays are released.

SECTION V
MAINTENANCE

5-1. GENERAL.

5-2. Since the stnadards are passive devices, a minimum of maintenance is required. With the exception of cleaning switch contacts, no maintenance on a regularly scheduled basis is required. Moving parts are lubricated at the factory and should require no further lubrication.

5-3. SWITCH.

5-4. Once every three to six months, clean switch contacts with a good grade of solvent such as alcohol or acetone. Relubricate contacts with a thin layer of vaseline.

5-5. SYNCHRONIZING ROTARY SOLENOID MODELS.

5-6. When the unit resets to 90°, 180°, or 270° instead of 0°, the unit has lost synchronism. Electrically, however, the unit will always reset to 0°: To regain synchronism, perform the following procedure:

a. Stop the unit at 85°, 175°, 265°, or 355° as indicated by the front panel readout.

b. Turn the ac power switch off, and wait approximately one minute.

c. Simultaneously hold down the local ADVANCE 5° button, and turn the ac power switch on. This will defeat the coarse switch advance circuit.

d. The unit will now stop 90° later, when the RESET TO ZERO button is held down. Repeat steps a, b, and c above until the unit stops at 0°.

5-7. REPAIRS.

5-8. If any repairs are made on the unit or if any parts are replaced, check the accuracy of the unit as outlined in Section VI. If any transformer problems are encountered it is recommended that the unit be returned to the factory for overhaul and recalibration.

SECTION VI
CALIBRATION

6-1. GENERAL.

6-2. The 2 seconds-of-arc accuracy of the resolver standard should be maintained for a period of not less than three years, provided that the unit is kept in a normal laboratory environment, has clean low-resistance contacts and does not suffer injury or insulation damage. Under these conditions, the unit should only require calibration every three years. Under more severe conditions, the calibration period must be shortened.

6-3. TEST EQUIPMENT.

6-4. To test the accuracy of the unit, the following test equipment (or equivalent) is required:

a. Phase Angle Voltmeter, Gertsch Model PAV. A phase-sensitive null indicator, such as Gertsch Model NI-3, may also be used.

b. Ratio Standard, Gertsch Model 1011.

6-5. ANGULAR ACCURACY.

6-6. To test the angular accuracy of the resolver standard, proceed as follows:

a. Connect unit into test setup as shown in figure 6-1.

NOTE

Connect the ratio standard directly to the output terminals of the resolver standard to eliminate errors resulting from voltage drops in the interconnecting leads.

b. Adjust Phase Angle Voltmeter to measure in-phase voltage.

c. Set resolver standard to 0°.

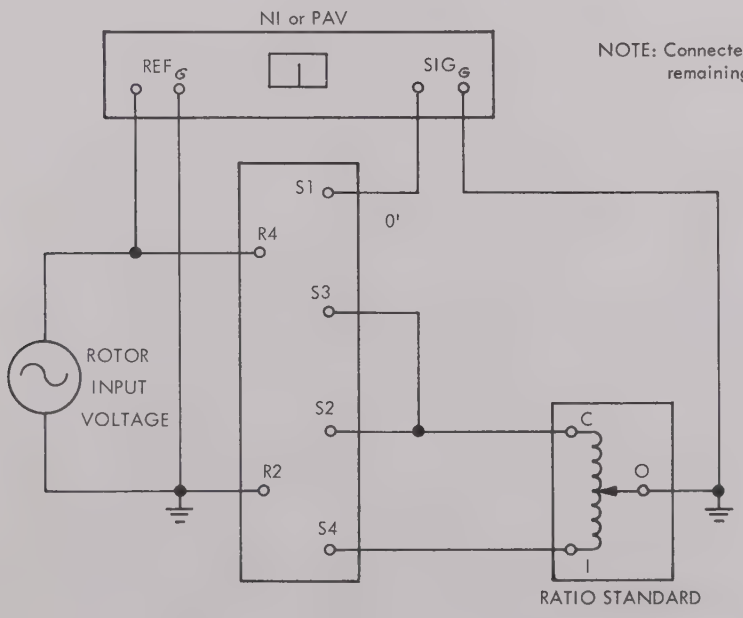
d. Adjust ratio standard as required to obtain a null on the Phase Angle Voltmeter.

e. The ratio standard shall indicate an output ratio (A theoretical) of 0.000000 within the limits set by the A column of table 3.

f. Repeat test at every 5° increment between 0° and 360°. Refer to Table 3 for the required output ratio and tolerances.

NOTE

The effective output impedance unbalance of the Synchro Standard may be readily checked by applying a BALANCED load to the output and measuring A. When testing with an inductive load, it is recommended that non-ferromagnetic inductors (GR type 1482 or equivalent) be used to prevent output voltage variations from changing the inductance of the load.



NOTE: Connected for measurements between 0° and 40°. For remaining measurements, connect as follows:

θ	0'	C	I	C
0° to 40°	S1	S2	S4	S3
45° to 85°	S4	S2	S1	S3
90° to 130°	S2	S3	S1	S4
135° to 175°	S1	S3	S2	S4
180° to 220°	S3	S4	S2	S1
225° to 265°	S2	S4	S3	S1
270° to 310°	S4	S1	S3	S2
315° to 355°	S3	S1	S4	S2

Figure 6-1. Angular Accuracy Test Setup

Table 3. Angular Accuracy

θ								$A_{theoretical}$	$\Delta A_{(ppm)}$
0		90		180		270		0.000000	9
5	85	95	175	185	265	275	355	0.087489	9
10	80	100	170	190	260	280	350	0.176327	10
15	75	105	165	195	255	285	345	0.267949	10
20	70	110	160	200	250	290	340	0.363970	11
25	65	115	155	205	245	295	335	0.466308	11
30	60	120	150	210	240	300	330	0.577350	13
35	55	125	145	215	235	305	325	0.700208	14
40	50	130	140	220	230	310	320	0.839100	16
	45		135		225		315	1.000000	19

SECTION VII
SCHEMATIC DIAGRAMS

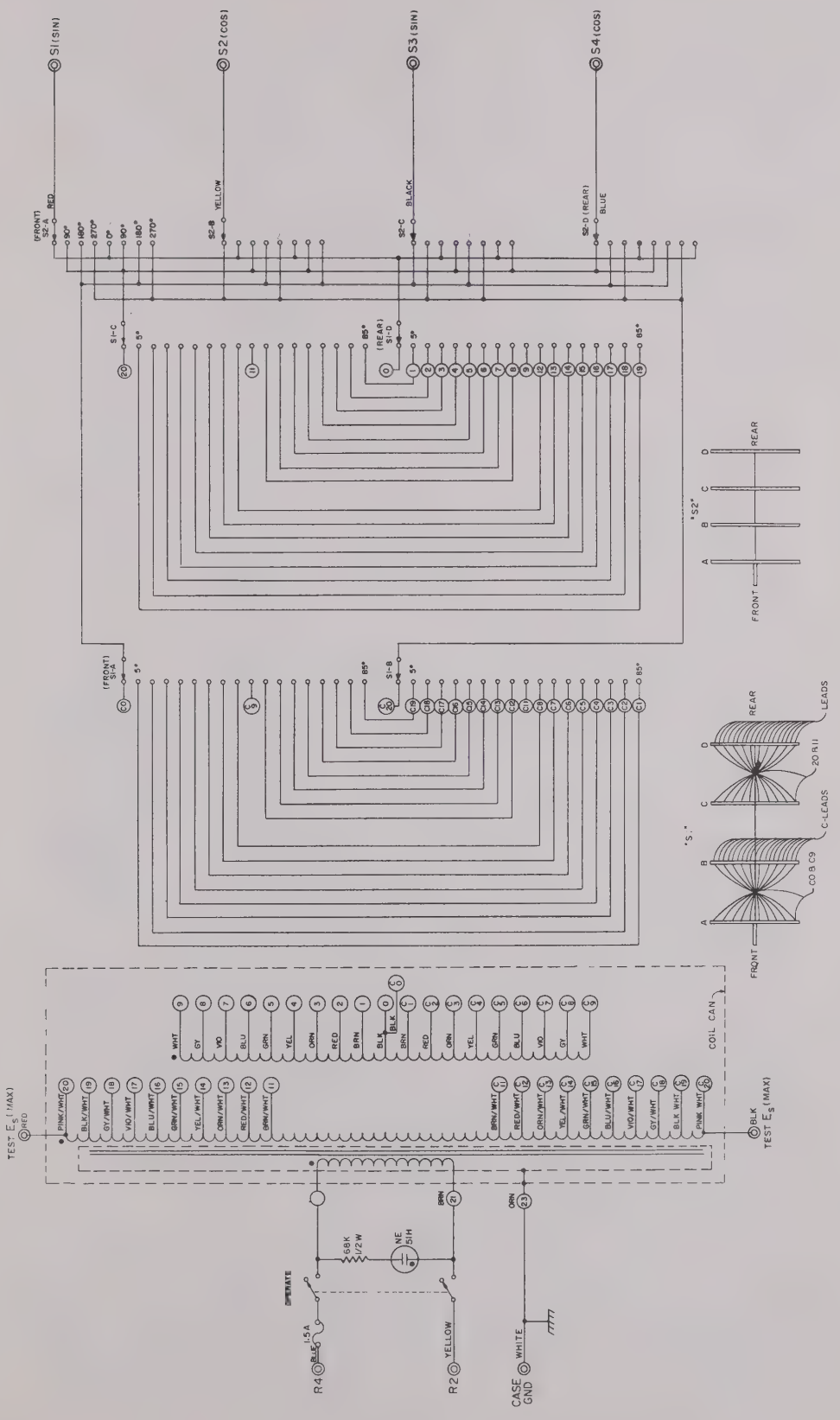


Figure 7-1. Typical Schematic, Knob Control Model

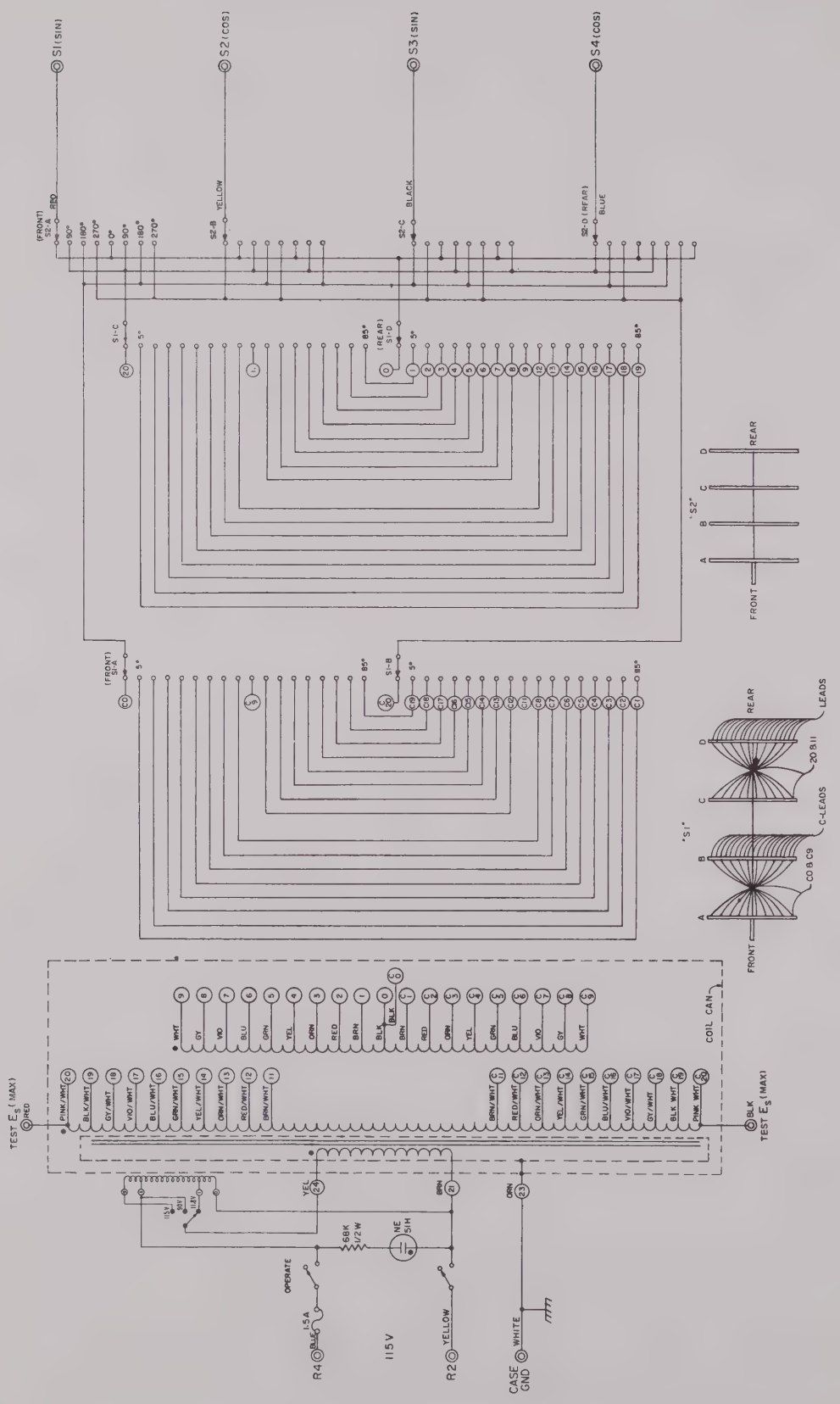


Figure 7-2. Typical Schematic, Knob Control, Selectable Output Voltage

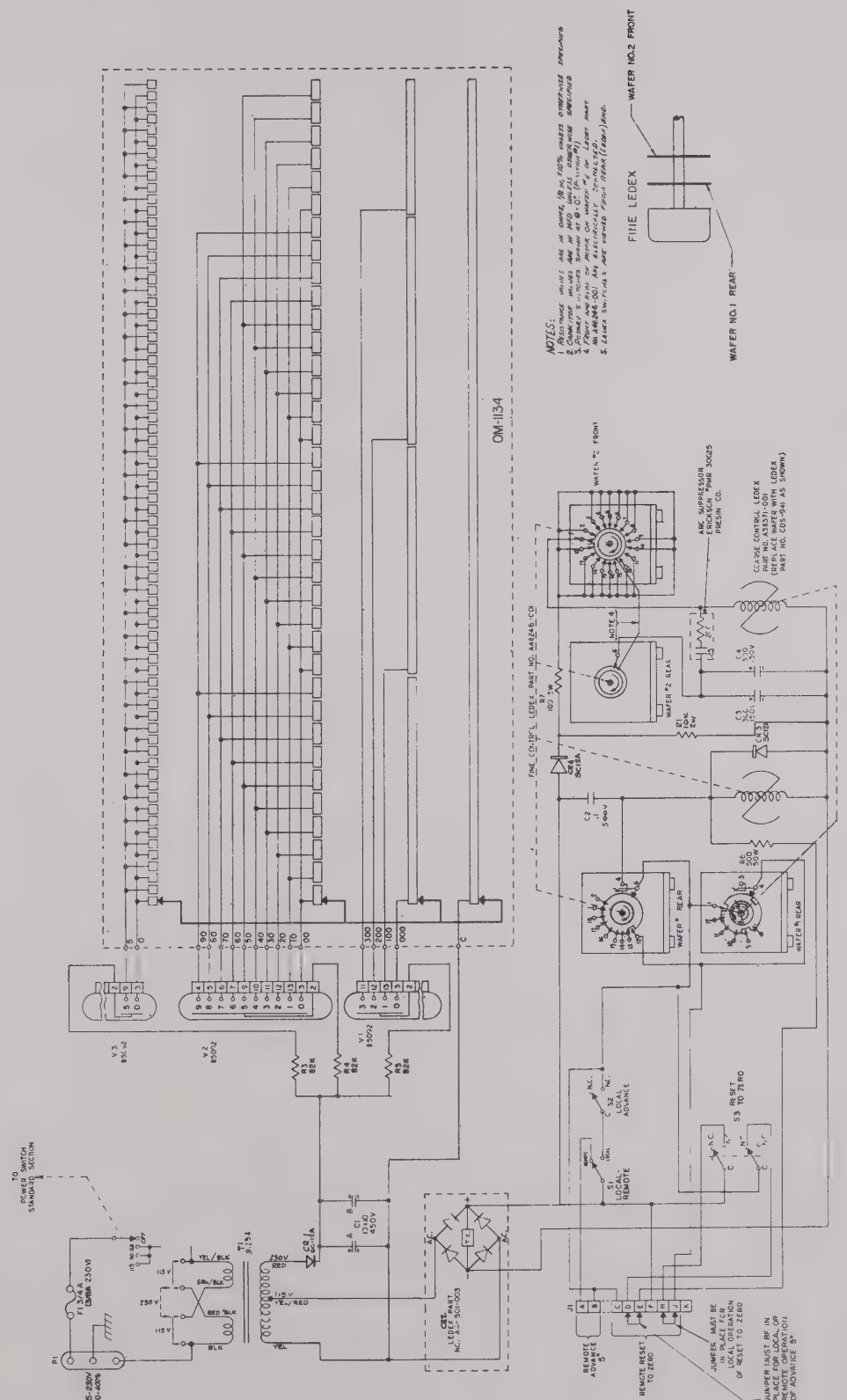


Figure 7-3. Typical Schematic, Rotary Solenoid Model Control Section

SECTION VIII
PARTS LIST

TWO-KNOB CONTROL MODELS

ITEM	PART NO.	MFG	RS-1	RS-2	RS-2A	RS-2B	RS-834	RS-1268	RS-1307			
Binding Post, Red	DF30RC	Superior	3	3	3	3	3	3	3			
Binding Post, Black	DF30BC	Superior	3	3	3	3	3	3	3			
Binding Post, Blue	DF30BLC	Superior	4	4	4	4	4	4	4			
Binding Post, Yellow	DF30YC	Superior	4	4	4	4	4	4	4			
Binding Post, White	DF30WTC	Superior	2	2	2	2	2	2	2			
COARSE SWITCHING CONTROL												
Knob, Bar	OP1	Gertsch	1	1	1	1	1	1	1			
Dial Assembly	AA837	Gertsch	1	1	1	1	1	1	1			
Switch	SW161	Gertsch	1	1	1	1	1	1	1			
FINE SWITCHING CONTROL												
Knob, Bar	OP1	Gertsch	1	1	1	1	1	1	1			
Dial Assembly	AA512-1	Gertsch	1	1	1	1	1	1				
Dial Assembly	AA512-3	Gertsch							1			
Switch	SW162	Gertsch	1	1	1	1	1	1	1			
Transformer Assembly	AA616-1	Gertsch	1				1					
Transformer Assembly	AA616-3	Gertsch		1								
Transformer Assembly	AA616-3	Gertsch				1		1				
Transformer Assembly	AA616-4	Gertsch			1							
Transformer Assembly	AA845-3	Gertsch					1					
Transformer Assembly	AA932-1	Gertsch							1			
Fuse Holder	342004	Littelfuse	1	1	1	1	1	1	1			
Fuse, 1-1/2 amp	MDL 1-1/2	Bussmann	1	1	1	1	1	1	1			
Switch, Toggle, DPDT	2BL6273	Carling	1	1	1	1	1	1	1			
Light Assembly, Red	VM312-6	Marco	1	1	1	1	1	1	1			
Lamp	1819	GE	1				1					
Lamp	NE51H	GE		1	1	1		1	1			
Resistor, Composition, 68K ±10%, 1/2W				1	1	1		1	1			

ITEM	PART NO.	MFG	RS-1	RS-2	RS-2A	RS-2B	RS-834	RS-1268	RS-1307			
Switch	SW56-1	Gertsch			1							
Knob	AC95	Gertsch			1							

SECTION IX
PARTS LIST

ONE-KNOB CONTROL MODELS

ITEM	PART NO.	MFG	RS-4	RS-4B	RS-5	RS-5A	RS-5A/2	RS-1228L	RS-1323	RS-1327	RS-1435	RS-1520	
Binding Post, Red	DF30RC	Superior	3	3	3	3	2	2	3	3	3	3	
Binding Post, Black	DF30BC	Superior	3	3	3	3	2	2	3	3	3	3	
Binding Post, Blue	DF30BLC	Superior	4	4	4	4	2	2	1	1	4	4	
Binding Post, Yellow	DF30YC	Superior	4	4	4	4	2	2	1	1	4	4	
Binding Post, White	DF30WTC	Superior	2	2	2	2	1	1	1	1	2	2	
Switching Assembly	AA605	Gertsch	1	1	1	1			1	1	1	1	
Switching Assembly	AA605-1	Gertsch					1	1					
Switch, Coarse	SW147	Gertsch	1	1	1	1	1	1	1	1	1	1	
Switch, Fine	SW148	Gertsch	1	1	1	1	1	1	1	1	1	1	
Knob	AC74	Gertsch	1	1	1	1	1	1	1	1	1	1	
Transformer Assembly	AA616-1	Gertsch	1										
Transformer Assembly	AA616-3	Gertsch			1								
Transformer Assembly	TA401	Gertsch										1	
Transformer Assembly	AA846-3	Gertsch						1					
Transformer Assembly	TA383	Gertsch									1		
Transformer Assembly	TA363	Gertsch		1									
Transformer Assembly	AA616-2	Gertsch											
Transformer Assembly	AA616-4	Gertsch				1							
Transformer Assembly	AA812	Gertsch					1		1	1			
Switch, toggle, SPDT	6AT6	Micro-switch					1	1					
Fuse, 1-1/2 amp	MDL 1-1/2	Bussmann	1	1	1	1	1	1	1	1	1	1	
Fuse Holder	342004	Littelfuse	1	1	1	1	1	1	1	1	1	1	
Switch, toggle, DPDT	2BL6273	Carling	1	1	1	1					1	1	
Light Assembly, Red	VM312-6	Marco	1	1	1	1					1	1	
Lamp	1819	GE	1	1							1	1	
Lamp	NE51H	GE			1	1							
Lamp	NE2J	GE					1	1	1	1			

ITEM	PART NO.	MFG	RS-4	RS-4B	RS-5	RS-5A	RS-5A/2	RS-1228L	RS-1323	RS-1327	RS-1435	RS-1520	
Resistor, composition, 68K±10%, 1/2W					1	1	1	1	1	1			
Switch	SW56-1	Gertsch				1							
Knob	AC95	Gertsch				1	1		1	1			
Switch	SW165	Gertsch					1		1	1			
Light Assembly, Red	145-5036-991	Dialight					1	1	1	1			

SECTION X
PARTS LIST

ROTARY SOLENOID CONTROL MODELS

ITEM	REF. DESIG.	PART NO.	MFG	RS-7	RS-8	RS-8A	RS-8B	RS-1553		
Binding Post, Red		DF30RC	Superior	3	3	3	3	3		
Binding Post, Black		DF30BC	Superior	3	3	3	3	3		
Binding Post, Blue		DF30BLC	Superior	4	4	4	4	4		
Binding Post, Yellow		DF30YC	Superior	4	4	4	4	4		
Binding Post, White		DF30WTC	Superior	2	2	2	2	2		
Switch Assembly, Coarse		SW186	Gertsch	1	1	1	1	1		
Switch Assembly, Fine		SW187	Gertsch	1	1	1	1			
Switch Assembly, Fine		SW240	Gertsch					1		
Switch Assembly, Nixie		AA1062-1	Gertsch	1	1	1	1			
Transformer Assembly			Gertsch	1						
Transformer Assembly			Gertsch		1					
Transformer Assembly			Gertsch				1			
Transformer Assembly		TA372	Gertsch			1		1		
Power Cord	P1	17406-S	Belden	1	1	1	1	1		
Fuse, 0.75 amp (115 vac)	F1	Type AGC	Bussmann	1	1	1	1	1		
Fuse, 0.375 amp (230 vac)	F1	Type AGC	Bussmann	1	1	1	1	1		
Fuseholder	XF1	342004	Littelfuse	2	2	2	2	2		
Switch, Power		SW97	Gertsch	1	1		1			
Switch, Power		SW246	Gertsch			1		1		
Terminal Strip		1774-5101-P24	Cinch	1	1	1	1	1		
Strap, Terminal strip		5-101	Cinch	1	1	1	1	1		
Transformer, Power	T1	91234	Triad	1	1	1	1	1		
Rectifier, Bridge	CR2	A-46501-003	Ledex	1	1	1	1	1		
Switch, Pushbutton	S2, S3	2PB11	Micro-switch	2	2	2	2	2		
Switch, Local-remote	S1	112-73	Carling	1	1	1	1	1		
Lamp, Nixie	V1, V2, V3	B5092	Burroughs	3	3	3	3	3		
Socket, Lamp		SK112	Cinch	3	3	3	3	3		

ITEM	REF. DESIG.	PART NO.	MFG	RS-7	RS-8	RS-8A	RS-8B	RS-1553		
Connector, Socket	J1	126-221	Amphenol	1	1	1	1	1		
Connector, Plug		126-220	Amphenol	1	1	1	1	1		
Knob, Power		AC95	Gertsch	1	1	1	1	1		
Fuse, 1-1/2 amp		MDL 1-1/2	Bussmann	1	1	1	1	1		
Lamp		NE2J	GE		1	1	1	1		
Lamp		327	GE	1						
Lamp Assembly		145-5036-991	Dialco	1	1	1	1	1		
CIRCUIT BOARD ASSEMBLY										
Capacitor, 10 x 10 uf	C1	BBRD1145	Cornell-Dublier	1	1	1	1	1		
Capacitor, 0.1 uf	C2	5HK-P10	Sprague	1	1	1	1	1		
Capacitor, 300 uf	C3, C4	BR30015	Cornell-Dublier	2	2	2	2	2		
Diode	CR1, CR3, CR4	SC-12A	Sentec	3	3	3	3	3		
Resistor, comp, 10K, 2W	R1			1	1	1	1	1		
Resistor, comp, 39K, 1W	R2			1	1	1	1	1		
Resistor, comp, 82K, 1/2W	R3, R4, R5			3	3	3	3	3		
Resistor, wirewound, 500 ohms, ±10%, 50W	R6	B-50	Dalohm	1	1	1	1	1		
Resistor, comp, 100 ohms, 5W	R7			1	1	1	1	1		
ARC Suppressor		PMR-30025	Erickson	1	1	1	1	1		

SECTION XI
PARTS LIST

RELAY CONTROL MODELS

ITEM	PART NO.	MFG	RS-10	RS-11	RS-11A	RS-11B						
Binding Post, Red	DF30RC	Superior	3	3	3	3						
Binding Post, Black	DF30BC	Superior	3	3	3	3						
Binding Post, Blue	DF30BLC	Superior	4	4	4	4						
Binding Post, Yellow	DF30YC	Superior	4	4	4	4						
Binding Post, White	DF30WTC	Superior	2	2	2	2						
Relay	7101101-1	Pacific Scientific	16	16	16	16						
Transformer Assembly		Gertsch	1		1							
Transformer Assembly		Gertsch		1								
Connector, Socket	XMRE-42-PF2016	Winchester	1	1	1	1						
Connector, Plug	XMRE-42-SC1046	Winchester	1	1	1	1						
Diode	DI56	Diodes, Inc.	8	8	8	8						
Fuse, 1-1/2 amp	MDL 1-1/2	Bussmann	1	1	1	1						
Lamp	NE51H	GE		1	1	1						
Lamp Assembly, Red	VM312-6	Marco	1	1	1	1						
Switch, Toggle	2BL6273	Carling	1	1	1	1						
Lamp	1819	GE	1									
Switch	SW56-1	Gertsch			1							
Fuseholder	342004	Littelfuse	1	1	1	1						
Knob	AC95	Gertsch			1							

SECTION XII
PARTS LIST

MODELS RS-1224 AND RS-1224R

ITEM	PART NO.	MFG	RS-1224	RS-1224R
Binding Post, Red	DF30RC	Superior		5
Binding Post, Black	DF30BC	Superior		5
Binding Post, Blue	DF30BLC	Superior		2
Binding Post, Yellow	DF30YC	Superior		2
Binding Post, White	DF30WTC	Superior		2
Connector, Electrical	MS3100R20-27P		1	
Fuse, 0.5 amp	MS90078-7-1		1	
Fuse, 0.5 amp	AGC 1/2	Bussmann		1
Fuseholder	HKL-E-AA	Bussmann	1	
Fuseholder	342004	Littelfuse		1
Switch, Toggle, DPDT	MS35059-23		1	
Switch, Toggle, DPDT	2BL6273	Carling		1
Lamp, Glow	NE2D	GE	1	
Lamp, Glow	NE51H	GE		1
Light Assembly	137-8536-936	Dialco	1	
Light Assembly	VM312-6	Marco		1
Resistor, composition, 150K±10%, 1/2W	MS35043-139		1	
Resistor, composition, 68K±10%, 1/2W				1
Switching Assembly	AA605-2	Gertsch	1	
Switching Assembly	AA605-1	Gertsch		1
Switch, Coarse	SW147	Gertsch	1	1
Switch, Fine	SW148	Gertsch	1	1
Knob	AC74	Gertsch	1	1
Transformer Assembly	TA593	Gertsch	1	
Impedance Network	AA955	Gertsch	1	
Transformer Assembly	TA403	Gertsch		1
Cable Assembly	AA921	Gertsch	1	
Connector	MS3106R-20-27S		1	
Connector	MS3106R-20-27P		1	

ITEM	PART NO.	MFG	RS-1224	RS-1224R
Case	AA919	Gertsch	1	

APPENDIX I

AN ANALYSIS OF RESOLVER STANDARDS

The following figure illustrates the basic circuitry common to all Gertsch Resolver Standards:

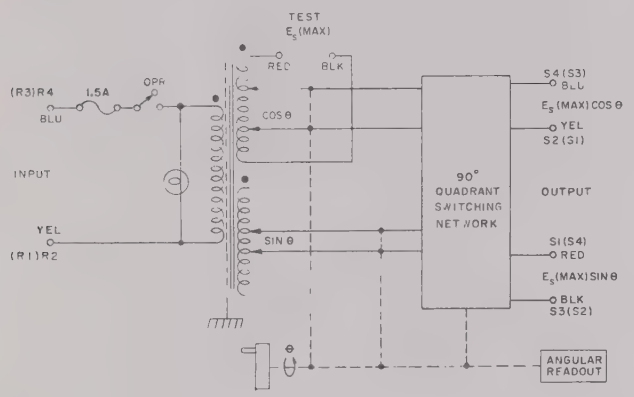


FIGURE 14. *Resolver Standard Block Diagram.*

Operational versatility of the Resolver Standard is increased by the use of two sets of terminal identifications. The input identification selected [R2-R4 or (R3)-(R1)] determines the output identification markings to be used by the operator. The binding posts are color coded per Mil-S-22347 and Mil-R-21530D, for the terminal identifications not parenthetically enclosed, i.e. R2-R4 input.

The phase relationships of the output voltages relative to the input voltage, conform to Mil-S-22347 and Mil-R-21530D for both sets of terminal identifications. That is:

$$E_{S1\text{-}S3} = N\,(E_{R1\text{-}R3}\ \cos\Theta - E_{R2\text{-}R4}\ \sin\Theta) \qquad (25)$$

$$E_{S2\text{-}S4} = N\,(E_{R2\text{-}R4}\ \cos\Theta + E_{R1\text{-}R3}\ \sin\Theta), \qquad (26)$$

where N is the transformation ratio of the Resolver Standard, and Θ is positive for CCW rotation from electrical zero (EZ), when viewed from the shaft end. The standard outputs of an RX (and RS therefore) are shown in figure 15 for R2-R4 excitation.

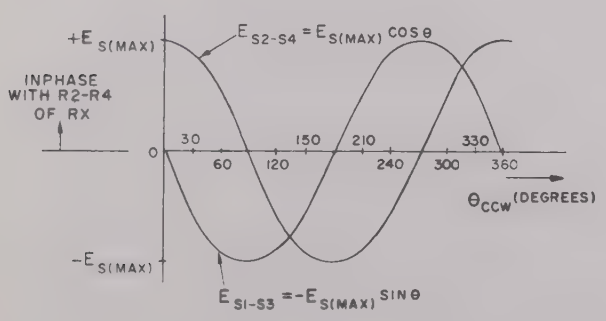


FIGURE 15. *Standard Resolver Control Transmitter (RX) Outputs as a Function of CCW Rotation From Electrical Zero (EZ), With R2-R4 Excited.*

The equivalent angular position of a Resolver Standard is uniquely and completely defined as a function of the ratio of the output voltages to each other:*

$$E_{S3\text{-}S1} = NE_{R2\text{-}R4}\ \sin\Theta \qquad (27)$$

$$E_{S2\text{-}S4} = NE_{R2\text{-}R4}\ \cos\Theta. \qquad (28)$$

Therefore, ideally:

$$A = \tan\Theta, \qquad (29)$$

where $A \equiv \dfrac{E_{S3\text{-}S1}}{E_{S2\text{-}S4}}$.

The relationship between a deviation in ratio and an equivalent angular error is derived by differentiating equation (29) with respect to Θ and converting to PPM and seconds-of-arc.

$$\Delta\Theta_{\text{(seconds)}} = \frac{\Delta A_{\text{(PPM)}}}{4.85\ \sec^2\Theta}. \qquad (30)$$

The maximum effect of loading on the accuracy of a Resolver Standard may be calculated from the following approximation:

$$\Delta\Theta_{MAX\,(sec)} \cong \pm\left[\text{Real Part Of } \left|\frac{Z_{O\,(unbalance)}}{Z_{SO}}\right| \times 10^5 - 2\right], \qquad (31)$$

where Z_{SO} is the stator impedance of the load, with the rotor open, at 0.707 $E_{S\,(max)}$.

The $Z_{O\,(unbalance)}$ of a Resolver Standard may be approximated at frequencies other than the nominal, by assuming the j component to be directly proportional to frequency.

The maximum line current from the primary and secondary of a Resolver Standard may be calculated from the following approximations:

$$I_{P\,(max)} \cong \frac{NE_{S\,(max)}}{Z_{SO}} \text{ at any angle, and} \qquad (32)$$

$$I_{S\,(max)} \cong \frac{E_{S\,(max)}}{Z_{SO}} \text{ at } 0°,\ 90°,\ 180°, \text{ and } 270°. \qquad (33)$$

* For this reason, the deviation in transformation ratio from the nominal as a function of angle does not affect the angular accuracy.

APPENDIX II

APPLICATION DATA

TESTING DATA-TRANSMISSION SYNCHROS AND RESOLVERS FOR ANGULAR ACCURACY

GENERAL

The function of data-transmission synchros and resolvers is to transmit angular position from one physical location to another via three or four wires. Synchros have the advantage over resolvers in that one less wire is required; however, it is more difficult to manufacture high accuracy synchros, because of their more complex winding configuration.

DEFINITION — ELECTRICAL ERROR

The angular accuracy of a data-transmission synchro or resolver is briefly defined as the difference between the mechanical position and the electrical position. This difference, expressed in angular units, is referred to as the Electrical Error of a synchro or resolver.

CONTRIBUTING ERRORS

Electrical Error is a result of the combined affect of several measurable errors. The following parameters are all possible contributors:

1. Transformation ratio unbalance.
2. Variation in phase shift.
3. Null spacing error.
4. Inter-axis error.
5. Functional error.

The above parameters are normally not tested individually for data-transmission synchros and resolvers, since it is only the affect that they have on the Electrical Error that is of importance. Note, that is is possible to have a large Functional Error and zero Electrical Error, if the *ratio* of the output voltages to each other is perfect.

By analyzing an Electrical Error curve, a manufacturer can determine the manufacturing errors:

TABLE I

Types of Electrical Error Curves Resulting From Various Manufacturing Errors.

Type of Error Curve	Manufacturing Errors
One cycle	Rotor eccentricity
Two cycle	Stator out-of-round. Unbalanced interwinding capacitance.
High Frequency	Design, since stator and rotor must be made up of laminations having a discrete number of slots.

ELECTRICAL ERROR SPECIFICATION

There are two ways of specifying Electrical Error: (1) *Maximum error* and (2) *Error spread. Maximum error* is the maximum positive or negative Electrical Error, measured over a full 360° of shaft rotation. Depending upon the origin of the error curve, it is possible to obtain two different interpretations of *maximum error.* Military specifications state that the origin of the error curve shall be at EZ, as shown in figure 1 (solid-line curve).

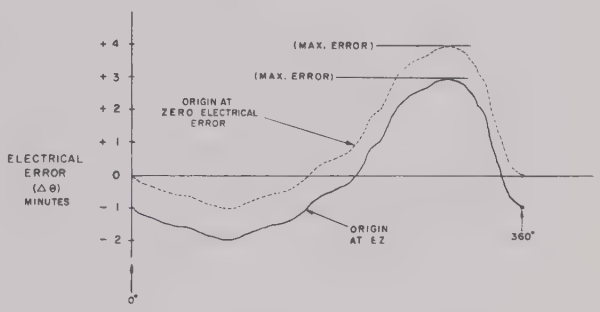


FIGURE 1. *Error Curves With Origin at EZ, and With Origin at Zero Electrical Error.*

Note, that is is possible for a synchro or resolver to have an Electrical Error at EZ. The *maximum error* for the solid-line curve shown is 3 minutes; however, if the origin is chosen at zero Electrical Error, the *maximum error* is equal to 4 minutes. The latter technique is, of course, the simpler and is used whenever possible.

The *error spread* is the sum of the maximum positive and maximum negative errors. Regardless of where the origin is chosen, the *error spread* is the same. Therefore, the origin should always be chosen at zero Electrical Error, since the test procedure is simplified. In the above example, the *error spread* is 5 minutes. As a rule-of-thumb, the *error spread* is approximately equal to 1½ times the *maximum error* from EZ.

ELECTRICAL ZERO

All Electrical Error tests are started at the approximate electrical zero (EZ) point. Coarse EZ of synchros and resolvers is usually indicated by a scribed radius on the exposed shaft end, which is lined up with an arrow stamped on the stator.

This EZ alignment procedure does *not* indicate that the unit will have the proper output phase relationships when the shaft is rotated in either direction. This so-called phasing test is actually performed during the Electrical Error test. If the unit under test and the test instrument must be rotated in opposite directions, the phasing is incorrect.

The following diagrams illustrate the phase relationships at EZ, for the different types of synchros and resolvers:

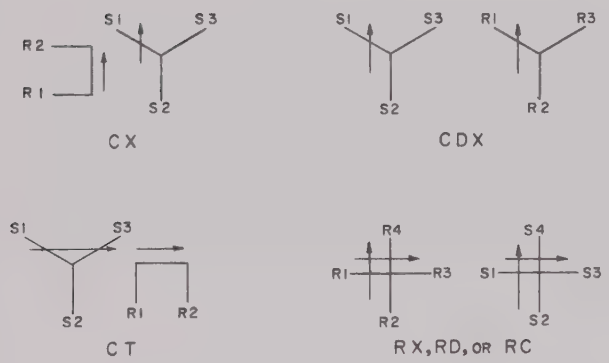


FIGURE 2. *Synchro and Resolver Phase Relationships at EZ.*

TEST CIRCUITS

The procedure for measuring Electrical Error requires either a Synchro/Resolver Standard or a Bridge, as specified in the following table:

TABLE II

Test Instruments Required for Electrical Error Measurement of Various Units.

Type of Unit to be Tested	Test Instrument Required for Electrical Error Measurement			
	SYNCHRO STANDARD	SYNCHRO BRIDGE	RESOLVER STANDARD	RESOLVER BRIDGE
CX		X		
CDX (stator)	X			
CDX (rotor)		X		
CT	X			
RX				X
RD (stator)			X	
RD (rotor)				X
RC			X	

Circuits for the above tests are illustrated in the SS, SB, RS, and RB sections of this catalog. The R1 and R3 leads shown in the CDX (rotor) and RD (rotor) test circuits may appear to be reversed. This reversal, however, is necessary in order to provide an *increasing* angle to the bridge as the shaft angle is increased. This is a direct result of the fact that differentials *subtract* from the angle applied to their input as their shaft angle is increased (rotated CCW as viewed from the shaft end), if R1 is connected to S1 and R3 is connected to S3 of a control transformer.

TEST METHODS

Two test methods exist for measuring Electrical Error: (1) Proportional Voltage Nulling Method, and (2) Proportional Voltage Gradient Method. Both methods are described in military specifications.

The Proportional Voltage Nulling Method requires the use of the Dividing Head vernier for obtaining an exact null on the Phase Angle Voltmeter. The Electrical Error at each position is then read on the vernier dial.

The Proportional Voltage Gradient Method is several times faster than the nulling method. Since the error voltage gradient of a control transformer, or a control differential transmitter (rotor) is the same at each angle, and is linear for quite a large angular error ($\triangle\theta = 5°$ causes only .13% error), it follows that the Electrical Error can be read directly in terms of voltage. A Phase Angle Voltmeter with a variable range control is very advantageous for this application, because any *maximum error* may be adjusted to correspond to full-scale deflection. Therefore, it is possible to record Electrical Error at each angle as a percentage of the maximum permissible Electrical Error, or directly from the calibrated scale if the selected full-scale Electrical Error is a multiple of 1 or 3.

The Phase Angle Voltmeter is calibrated by, first, obtaining a null with the Dividing Head vernier, and then purposely introducing (with the vernier) the exact amount of Electrical Error, desired to correspond to full-scale. Next, the variable range control on the PAV is adjusted for full-scale deflection, and the vernier is *then* returned to the null position. The test is performed by advancing the Dividing Head and the Bridge or Standard, in 5° steps, 72 times. At each 5° step the Electrical Error is displayed on the Phase Angle Voltmeter.

It should be noted that a *compensated* Synchro or Resolver Bridge must be employed when using the Proportional Voltage Gradient Method to test control transmitters, or control differential transmitters (rotor).

IMPORTANCE OF ϕ

The reference axis for the phase-sensitive detector must be along the inphase output axis of the synchro or resolver. Otherwise, a portion of the fundamental null voltage (V_Q) will appear to be a part of the inphase output signal. As an example, consider a typical 26V CX with an $E_{S(max)}$ of 11.8V:

Fund. Null (V_Q) = 20MV
Phase Shift (ϕ) = 10°

If the input axis is chosen as the reference axis, a small amount of signal voltage is required to cancel the portion of V_Q which is "inphase" with the input.

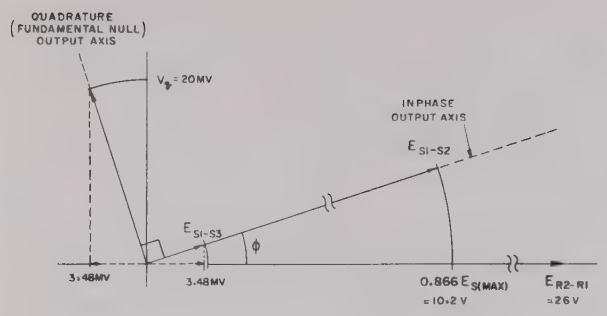


FIGURE 3. *CX Outputs Near EZ.*

As can be seen from figure 3, the amount of signal voltage (E_{S1-S3}) necessary is:

$$E_{S1-S3} = \frac{20 \times \sin 10^\circ}{\cos 10^\circ} = 3.54 \text{ MV}. \qquad (1)$$

This corresponds to a value of Θ equal to:

$$\Theta = \sin^{-1} \frac{3.54\text{MV}}{11.8\text{V}} \cong 1' \qquad (2)$$

Therefore, the angle of the CX is approximately one minute from actual EZ.

A rule-of-thumb frequently used for specifying fundamental null voltage is that it shall be less than 50% of the maximum permissible Electrical Error in terms of voltage. The error voltage gradient of the CX in the above example is:

$$\frac{\triangle V}{\triangle \Theta} = 11.8 \sin 1^\circ = 206 \text{ MV/degree} \qquad (3)$$

Therefore, the approximate permissible *maximum error* of the CX in the example above is:

$$\triangle\Theta = \frac{2 \times 20 \text{ MV}}{206 \text{ MV/degree}} \cong .2^\circ = 12' \qquad (4)$$

Total null is, as a rule-of-thumb, allowed to be 50% greater than the fundamental null. This would amount to 30MV in the above example.

$\frac{\triangle V}{\triangle \Theta}$ MAGNITUDE AND PHASE

The magnitude of the error voltage gradient $\frac{\triangle V}{\triangle \Theta}$, or the "sensitivity" can be calculated from the equations in the following table for various error-sensing devices.

TABLE III

Error Voltage Gradient Equations for Various Error-Sensing Devices.

Error-Sensing Device (Stator Input / Rotor Output)	Error Voltage Gradient $\left(\frac{\triangle V}{\triangle \Theta}\right)$, or "sensitivity"		
	Volts/Degree	MV/Minute	μV/Second
CDX (stator),*	$.0151NE_{S\,(max)}$	$.252NE_{S\,(max)}$	$4.20NE_{S\,(max)}$
CT*	$.0174E_{R\,(max)}$	$.291E_{R\,(max)}$	$4.85E_{R\,(max)}$
SB,**	$.0174NE_{S(max)}$	$.291NE_{S\,(max)}$	$4.85NE_{S\,(max)}$
RB**	$.0174E_{R\,(max)}$	$.291E_{R\,(max)}$	$4.85E_{R\,(max)}$
RD (stator), RC	$.0174NE_{S\,(max)}$	$.291NE_{S\,(max)}$	$4.85NE_{S(max)}$
	$.0174E_{R\,(max)}$	$.291E_{R\,(max)}$	$4.85E_{R\,(max)}$

* The transformation ratio (N) of a CDX or CT, as defined by Mil-S-20708A, is equivalent to the rotor voltage at maximum coupling divided by 0.866 $E_{S(max)}$.

** Gertsch Compensated Synchro and Resolver Bridges have a transformation ratio (N) of 1.000. Note, that an SB with an N of 1.000 is equivalent to a CT with an N of 1.155.

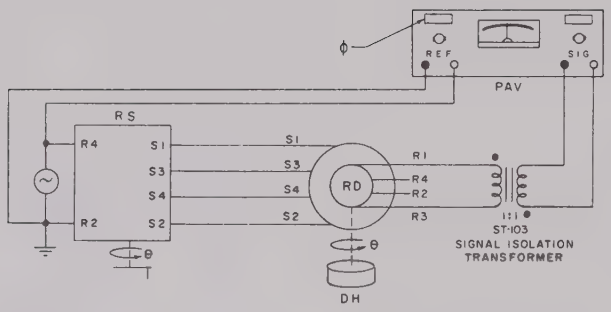
By observing the phase of the error voltage ($\triangle V$) relative to the reference voltage, it can be determined whether the equivalent angular position of the input signal to the error-sensing device (Θ_{elect}) is greater than, or less than, the angular position of the error-sensing device (Θ_{mech}).

TABLE IV

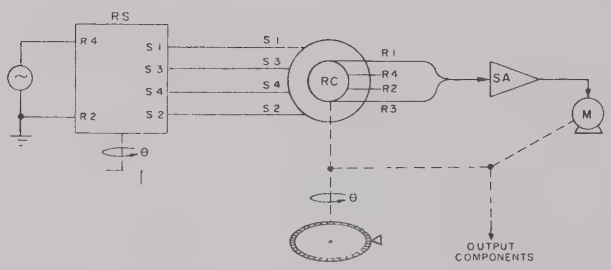
Phase Relationship Between Error Voltage and Reference Voltage for Various Error-Sensing Devices.

Error-Sensing Device	Θ_{elect} greater than Θ_{mech}
CT, SB	$\triangle V_{R2-R1}$ out-of-phase with E_{R2-R1}
CDX (stator)	$\triangle V_{R3-R1}$ out-of-phase with E_{R2-R1}
RD (stator), RB, RC	$\triangle V_{R3-R1}$ inphase with E_{R2-R4}, or $\triangle V_{R4-R2}$ inphase with E_{R3-R1}

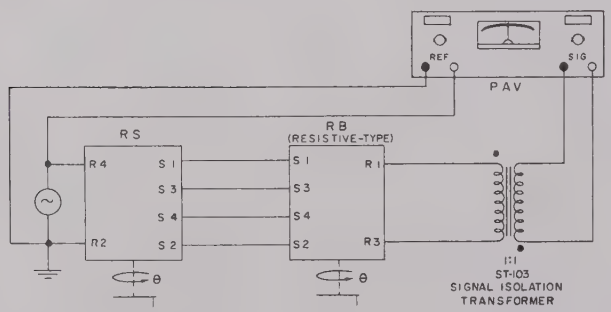
This phasing information is extremely important when trying to differentiate between true-null and false-null which are 180° apart. For example, if an SB is connected to the output of a CX, and the angle of the SB (Θ_{mech}) is purposely *increased* beyond null, Θ_{elect} is less than Θ_{mech} and $\triangle V_{R2-R1}$ should be *inphase* with E_{R2-R1}. If it is out-of-phase, the angle displayed on the SB is 180° from the true angular position of the CX.



RD (stator) (or RC) Angular Accuracy Test. Note, that either the "Proportional Voltage Nulling" or the "Proportional Voltage Gradient" method may be used.



Using an RS as a "Dummy Director" to Position a Single-Speed Servo.



Calibrating Lower-Precision Resistive-Type Resolver Bridges. Note, that the error voltage from the RB may be converted to an equivalent angular error

APPENDIX III

SYNCHRO AND RESOLVER TESTING

Synchro and Resolver Standards

Prior to the introduction of synchro and resolver standards, "master" transmitters were simulated with an ordinary synchro or resolver transmitter together with an angular positioning device, a synchro or resolver bridge, a phase-sensitive null detector, a bridging transformer, and a phase shifter. This technique required the operator to "calibrate" the transmitter against the bridge at *each* angle by adjusting the angular positioning device for a null on the detector. The purpose of the phase shifter, required by both military and commercial specifications, was to compensate for the time phase shift of the transmitter. The main disadvantages of this technique are that it is relatively slow and inaccurate, besides being difficult to operate, expensive, and quite space consuming. The inaccuracy of this method is due to several causes, such as operator error, drift, hook-up error, plus the specified error of the individual pieces of equipment.

The requirement for an efficient and accurate "master" synchro and resolver transmitter was met by a simple extension of the time-proven RatioTran® technique, pioneered by Gertsch over a decade ago. This device, which replaces all of the equipment required by the earlier technique, was soon termed a synchro or resolver standard. Basically, a Gertsch synchro or resolver standard consists of an extremely low phase shift transformer with a primary and one or two *isolated* secondaries respectively. The secondary has several precision taps which determine the angles available. Depending upon the particular model, angles may be selected by several techniques such as by turning one or more knobs, pulsing a rotary solenoid operated switch, or by energizing a relay.

Besides possessing a high degree of no-load accuracy (2 seconds-of-arc traceable to NBS) standards generally have a very low nominal output impedance, and an extremely low output impedance unbalance. This allows a normal load to be applied without significantly affecting the no-load accuracy. The output impedance of synchro and resolver standards is typically a few ohms; however, specific values of output impedance e.g., 50 + j50 ohms can be provided for applications where it may be desirable to actually simulate the output impedance of a synchro or resolver. In order to prevent angular errors due to loading from occurring, it is necessary for the output impedance of the standard to be balanced at each angular position. Output impedance unbalances as low as .01 + j.001 ohms are considered standard.

In addition to maintaining a high degree of accuracy under load, the standard may normally be operated over a wide voltage (10:1), and frequency range with very little degradation of accuracy. The frequency range of synchro and resolver standards extends from 30 cps to 10 KC or higher. Ideally, units are designed for a particular frequency; however, the useful frequency range for a particular unit generally extends to approximately two octaves (four times) above the design frequency. Operation below the design frequency will saturate the transformer, unless the input voltage is reduced in direct proportion to the frequency.

Normally, high accuracy resolver standard applications require that the outputs of the standard be isolated from each other. If the sine and cosine outputs of the standard are common, an unsymmetrical current will be forced to flow through the interwinding capacitance of the resolver under test; therefore, causing angular errors to occur which under actual conditions do not exist.

Synchro and Resolver Bridges

Basically there are two types of synchro and resolver bridges — the resistive (10K) and the inductive. Up until a few years ago, the resistive-type bridges were the only type of bridges available; however, the demand for higher input impedances, lower output impedances, and higher accuracies brought about another extension of the RatioTran technique — the inductive-type bridge. Actually, the term inductive-type is somewhat misleading, since the inductive-type bridge is normally operated in the vicinity of self-resonance. Therefore, the input impedance may be slightly capacitive, resistive, or slightly inductive. Obviously, the highest input impedance will be obtained at the resonant frequency.

Compared to resistive-type bridges, inductive-type bridges have an input impedance almost two orders of magnitude greater, and an output impedance approximately three orders of magnitude lower. The inherently high output impedance of the resistive-type bridge severely limits its application at high frequencies, since internal and external stray capacitances are more likely to alter the tapped ratios and the critical impedance balance of the four 10K resistors.

It is a fact that the input impedance of an inductive-type bridge is somewhat a function of voltage; therefore, it is difficult to maintain a real high degree of input impedance balance. However, it should be noted that the higher the input impedance, the less the effect of input impedance unbalance. In addition, $1/\sin 2\theta$ variations in input impedance unbalance are allowable without increasing the angular error.

Both the resistive and the inductive types of bridges are available either compensated or uncompensated. A compensated bridge has the same error voltage gradient at each angular position. Resistive-type bridges are compensated by using different resistive dividers at each angle, while the inductive-type are compensated with the use of a scaling transformer. The output impedance of the compensated resistive-type bridge is approximately four times higher than the uncompensated type.

An often overlooked accessory piece of equipment required for synchro and resolver bridges is a bridging transformer, when using a single-ended null detector. Grounding one terminal of the bridge output directly can cause apparent angular errors to occur. All Gertsch compensated bridges utilize a combination scaling and double-shielded bridging transformer. If a compensated resistive-type bridge is used, a bridging transformer with an input impedance of a megohm or more is required, otherwise the compensation will be affected due to loading. In addition, it may be necessary to use a bridging transformer which has been resonated, in order to prevent phase shift of the error voltage from the output of the resistive-type bridge.

Gertsch uses a unique resolver bridge circuit which provides two isolated and double-shielded inputs, plus an isolated and double-shielded output. In addition, the circuit employed is inherently compensated. Resistive-type 4-arm resolver bridges effectively interconnect the center taps of the two output windings of the resolver under test through a 2.5K ohm resistance which has no effect *if* the outputs of the resolver under test are balanced to each other.

Inductive-type bridges are ideally designed for a particular frequency; however, the useful frequency range generally extends from one octave below (one-half) to one octave above (twice) the design frequency. The frequency range of inductive-type bridges is from 30 cps to 10 KC, or higher. At frequencies below 1600 cps, input impedances as high as 800K are available. The input impedance obtainable at 10 KC is approximately 250K.

Another often-heard argument against resistive-type bridges is that 10K ohms is not a realistic load. In fact, the 10K ohm load can cause angular errors to occur which under actual conditions would never exist, since the load is normally quite inductive. This is particularly true when testing synchros and resolvers with a high output impedance. Testing under load is normally accomplished by simply connecting the actual load, e.g. a CT, in parallel with the input to the bridge. Therefore, if the load impedance is a few thousand ohms or higher the input impedance of the resistive-type bridge will alter the apparent load impedance seen by the component under test. The input impedance of the inductive-type bridge, however, can normally be neglected.

Ratio accuracies equivalent to 2 seconds-of-arc are easily obtained and maintained with inductive-type bridges, while 2 seconds-of-arc is quite difficult to maintain with resistive-type bridges due to aging, temperature coefficients, and accidental overloading. Overloading of a resistive-type bridge can be caused, for example, by accidentally shorting one of the stator input leads to one of the output terminals. Although an overload may not be sufficient to burn-out the bridge, it is quite possible to permanently change the tap ratios and the total resistance values of the four arms. A damaged bridge could go undetected for several months, until it's recalled for periodic "calibration."

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Whichever type of resolver bridge is used, resistive or inductive, the user should be certain not to use the type of bridge which commons the sine and cosine outputs of the resolver under test, unless large angular errors can be tolerated. Such errors are a function of the source impedance and the interwinding capacitance of the resolver under test, neither of which are generally known by the bridge user. Therefore, it is best to avoid this type of bridge entirely.

High Resolution Standards and Bridges

Conventional 5° resolution standards and bridges are generally inadequate for servo system or module testing, where convenient values of system parameters (knots, yards, etc.) are not even multiples of 5°. In general, high-resolution (.001°) decade standards and bridges are used: (1) As a distinctly superior system-error bridge, for measuring the output angle of synchros or resolvers which are an integral part of a system of sub-system; (2) for trouble-shooting sources of error in data transmission systems such as cable loading, gearing, dial readout, impedance unbalance, etc.; (3) to generate precise input angles to a system or sub-system; (4) to measure system sensitivity or response to small angular errors; (5) for measuring the drift or stability of a system about a particular point.

The theory of operation of these Gertsch instruments is basically the same as the 5° units, except that several precision transformers and switches have been added to effectively multiply the number of taps by 5,000 in order to provide .001° resolution.

A very important feature of the Gertsch decade bridges is their complete independence of synchro or resolver functional accuracy, transformation ratio, and phase shift, plus their completely passive circuitry. Absolutely no preliminary calibration manipulations are required.

Functional Accuracy Testing

The angular accuracy of a data-transmission synchro or resolver is based on the *ratio* of two output voltages to each other. The functional accuracy of a computational resolver, however, is based on the ability of each output winding, individually, to produce a voltage proportional to the sine or cosine of the shaft angle. The output 90° from minimum coupling is normally used as the reference voltage.

The procedure for measuring functional accuracy consists of setting up a voltage across a voltage divider which is equal in amplitude and phase to the output of the winding under test at 90° from minimum coupling. The output of the resolver at each angle is then bridged against the output of the voltage divider. A computational resolver with a functional accuracy of 0.05% would be allowed ± 500 ppm deviation from the theoretical sine or cosine value at each angle. Note, that the allowable *angular* error is a function of the angular position of the shaft. For example, a 0.05% functional error corresponds to an angular error of 1.7 minutes at 0°, and 3.4 minutes at 60°.

In practice, the above technique may be instrumented in either one of two ways. The first technique employs a Sine θ RatioTran (sine 0° to 90° in 5° steps), a Phase Angle Voltmeter (PAV), a conventional RatioTran, and an RC phase shifter. The functional error at each angular position is displayed on the PAV as an error voltage. For example, a 0.05% computational resolver with a maximum output of 15V, is allowed ± 7.5 mv at *each* angular position. With the variable range attenuator on the PAV, 7.5 mv can be set up to read full-scale on the 3 mv range. Therefore, the functional error at each angle can be read directly on the PAV meter.

The second technique utilizes a Gertsch Complex Ratio Bridge (Model CRB-2B) and a conventional RatioTran. The RatioTran is adjusted for a null on the CRB with the resolver set to 90° from minimum coupling. The inphase RatioTran on the CRB is adjusted for a null at each angle, and its deviation from the theoretical sine or cosine of the shaft angle is noted in ppm. The quadrature RatioTran at null, can be set up to indicate the phase shift from primary to secondary, directly in degrees.

Automatic Testing

Gertsch developed two lines of automatic synchro/resolver standards and bridges, the rotary solenoid type and the relay (programmable) type. Basically the rotary solenoid type is ideal for component angular accuracy tests, since the unit sequentially advances in 5° steps with each contact closure. On the other hand, the relay type is ideal for system testing where random access to several angles may be desired. Input commands can be in several forms such as BCD, straight binary, decimal, etc.

To accompany the rotary solenoid type units in automatic component tests, Gertsch developed an automatic dividing head. This automatic unit advances 5° every six seconds, and remains there for approximately 4 seconds. In addition to automatically advancing itself, it also advances the rotary solenoid standard or bridge, mutes the phase angle voltmeter, and lowers the pen on the DC recorder at the proper moment. The timing sequence for this remote control is programmed by cam-operated switches. The camshaft is driven from the same synchronous motor that drives the 5° indexing mechanism.

With the automatic test set-up above, it is possible to complete a 72 point angular accuracy test in less than 10 minutes including set-up time. If a strip chart recorder is used, a permanent record of the components error can also be made automatically. Manual techniques can take as long as an hour or more — even with an experienced operator.

Dividing Heads

Unlike most other test instruments used in angular accuracy tests, not all dividing head errors can be measured, or specified. The most common specification for dividing heads is the indexing accuracy. Indexing accuracies currently available range from 20 seconds-of-arc down to ¼ of a second-of-arc. Additional errors depend upon the way in which the component under test is mounted in the dividing head, and the environmental conditions. An ideal mounting technique is one which causes absolutely no end or radial loading of the rotor relative to the stator.

Some dividing head manufacturers employ a mounting technique which rigidly clamps the rotor and the stator of the component under test to the dividing head. It is extremely difficult for an average skilled operator to mount a component in this type of dividing head without causing any radial and/or end loading due to misalignment. An extremely important precaution which must be taken with this mounting technique is to make sure that all mounting surfaces are entirely free from dirt. In fact, it is almost a requirement that this type of dividing head be operated in a dust-free room. In addition, unless the component under test is geometrically perfect, i.e., there is no eccentricity in the rotor, the rotor axis is perpendicular to the mounting surface of the stator, etc., several seconds or possibly minutes-of-arc error can be created.

Gertsch's mounting technique consists of rigidly clamping the rotor, and effectively floating the stator. The only precaution that the operator must take is to be careful not to apply physical force to the component through the wires attached to the stator.

Phase Angle Voltmeters

The Phase Angle Voltmeter (PAV) is ideal for synchro and resolver angular accuracy tests, since an external phase shifter is not required in order to compensate for the time phase shift angle of the component under test. In addition, large amounts of quadrature (fundamental null) can be tolerated without affecting the accuracy of the inphase null.

The Gertsch PAV has several features designed to aid synchro and resolver angular accuracy testing. For example, when using the "Proportional Voltage Gradient Method" 3 minutes-of-arc may correspond to, say, 19.6 mv. However, with the variable attenuator on the front panel of the PAV, 19.6 mv can be set up to equal full scale deflection on the 10 mv scale. Thus, the angular error at each 5° point can now be read directly on the 3-0-3 scale of the PAV. Other features include plug-in, ±5% band-pass, filters from 200 cps to 10 KC, DC recorder output (±37.5 mv equals full scale on meter), optional meter relay plug-in to provide contact closures at + and — full scale deflection, variable reference angle from 0° to 360° continuously, variable attenuator — any voltage from 1 mv to 300V can be adjusted for full scale deflection, high quadrature rejection — overload lamp lights when the total input signal exceeds 10 times the range selector position.

Synchro and Resolver Specifications

Synchro and resolver specifications have made good progress in the last few years. Before that, resolver specifications were, for all practical purposes, non-existent. The worst result of this was the confusion generated for several years by not having a set of *standard* equations relating input and output voltages to each other, as a function of shaft position.

The Polaris resolver specification Mil-R-21530 (D) was the first universally accepted publication covering both data-transmission and computational type resolvers. Shortly thereafter, a *draft* copy of Mil-S-22347 (data-transmission resolvers only) was issued which agreed with Mil-R-21530's equations; however, a few months later Mil-S-22666 (computational resolvers only) came out, and disagreed with Mil-R-21530's equations. As a result, there is general agreement on the equations for data transmission type resolvers, and some disagreement on computational types. Mil-R-21530's equations would have been the easiest to standardize upon, since it specified the same equations for both types of resolvers. Incidentally Mil-S-22347 has never been released, although the draft was written three years ago.

The SAE specification ARP-461 (A) covers both data-transmission synchros and resolvers, and is in general agreement with all other specifications. An ARP computational resolver specification is in process, and the B revision to ARP-461 is well under way.

The specification Mil-S-20708 (B) (data-transmission synchros only) was recently revised with several minor refinements, one of which was to define the impedance Z_m.

Synchro and resolver standards, and inductive-type bridges are widely used for both military and commercial applications. In fact, a large number of these instruments are presently used in the most advanced guidance and fire control systems. However, neither the military or the commercial specifications have been brought up-to-date in this respect, even though these units have been in use for several years. The currently available specifications show only the obsolete "master" transmitter techniques, and the resistive-type bridges. The requirement for revising the current specifications is obvious, since at present there are no specifications which show what the values and tolerances of the various electrical parameters associated with these new units should be, and which circuit configurations are acceptable.

Future Trends

For obvious reasons, size 8 (approximately 0.8" in diameter) is fast becoming the most popular size component for new designs. Soon after that the trend will probably be toward size 5 components. With this trend toward smaller size components, will come a requirement for dividing heads which cause less and less radial and end loading.

Components with higher accuracies will of course become available; resolvers with one second-of-arc accuracy are not too difficult to imagine. Higher impedance values, and higher frequencies will also become more common.

The Hall-effect synchros and resolvers may go into production in a few years, assuming that the temperature sensitivity and output voltage limitation problems are solved. With them will come smaller sizes, lower voltages, and wider frequency ranges (D.C. to megacycles).

Major improvements in test equipment design are most likely to occur in the high frequency and high resolution area; however, major improvements in other areas such as dividing heads are also quite probable. It should be pointed out though that the test equipment available today is still several steps ahead of the majority of components currently available.

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APPENDIX IV

DECREASING THE △N OF SS'S AND RS'S

GENERAL

Occasionally, it is desirable to compensate for the effective variation in transformation ratio (△N) of a Synchro or Resolver Standard, as a function of angular position. Of course when testing data-transmission synchro or resolvers for angular accuracy, this small (± 1% max.) variation has no effect, since it is the *ratio* of the output voltages to each other which determines the angular accuracy.*

TECHNIQUES

The most direct method of correcting for △N is to adjust the input voltage to the SS or RS at each angular position (see figure 1). A conventional RatioTran® is ideal for this, because of its high accuracy and resolution, plus its low output impedance. The techniques which follow illustrate and describe methods for obtaining the "Correction Ratios."

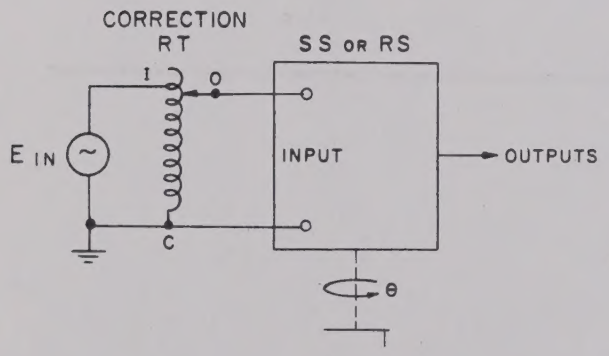

FIGURE 1. *Basic △N Correction Technique.*

With reference to figures 2 and 3, it should be noted that a precise $E_{s(max)}$ reference can be derived from the I-C terminals of the Correction RT, if all of the ratios in column (4) are multiplied by $\frac{E_{in}}{E_{s\,(max)}}$. Care should be taken not to apply excessive input voltage to the SS or RS, in order to avoid saturation. The technique described in figure 4 automatically provides a precise $E_{s(max)}$ reference across the input to the Correction RT; however, the input voltage limitations of the SS or RS should not be exceeded.

It may be necessary to remove the pilot light in the 26V units, in order to prevent loading of the Correction RT shown in figures 2 and 3.

* SS's and RS's can be supplied with △N's as small as .001%.

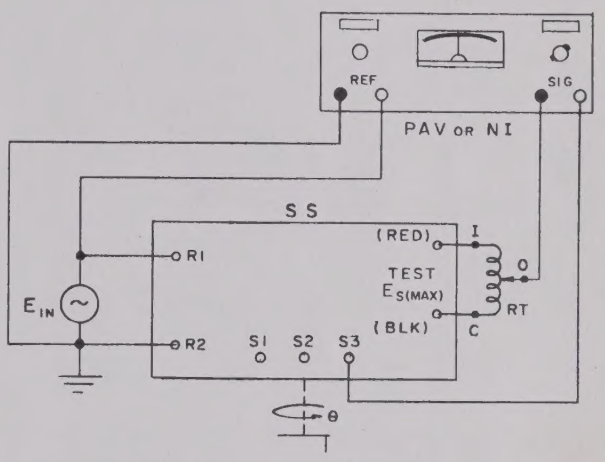

FIGURE 2. *SS "Correction Ratio" Technique.*

PROCEDURE

(1) Obtain an inphase null at each of the angles from 0° to 30° in the following table, and fill in columns (2), (3) and (4).

θ	RT (theoretical) (1)	RT (measured) (2)	△RT (1) - (2)=(3)	CORRECTION RT RATIO $1+\frac{(3)}{(1)}=(4)$
0	.866025			
5, 55	.819152			
10, 50	.766044			
15, 45	.707107			
20, 40	.642788			
25, 35	.573576			
30	.500000			

(2) Column (4) above gives the "Correction Ratios" for the RT in figure 1. Column (4) is also equal to $2-\frac{(2)}{(1)}$.

(3) For angles other than the above, subtract multiples of 60° to obtain an angle between 0° and 60°. To avoid correction ratios greater than unity, divide all the ratios in column (4) by the largest correction ratio obtained.

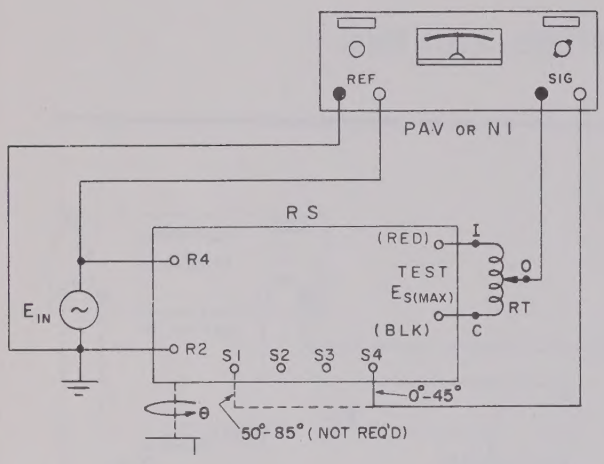

FIGURE 3. *RS "Correction Ratio" Technique.*

PROCEDURE

(1) Obtain an inphase null at each of the angles from 0° to 45° in the following table, and fill in columns (2), (3) and (4).

θ	RT (theoretical) (1)	RT (measured) (2)	△RT (1) - (2)=(3)	CORRECTION RT RATIO $1+\frac{(3)}{(1)}=(4)$
0	1.000000			
5, 85	.996195			
10, 80	.984808			
15, 75	.965926			
20, 70	.939693			
25, 65	.906308			
30, 60	.866025			
35, 55	.819152			
40, 50	.766044			
45	.707107			

(2) Column (4) above gives the "Correction Ratios" for the RT in figure 1. Column (4) is also equal to $2-\frac{(2)}{(1)}$.

(3) For angles other than the above, subtract multiples of 90° to obtain an angle between 0° and 90°. To avoid correction ratios greater than unity, divide all the ratios in column (4) by the largest correction ratio obtained.

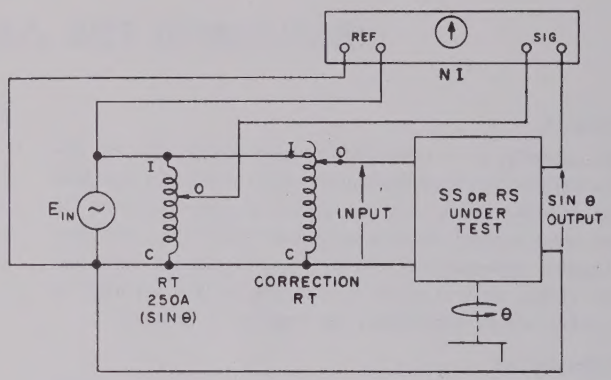

FIGURE 4. *SS or RS "Correction Ratio" Technique.*

PROCEDURE

(1) Set the Sin θ RT, and the unit under test to the same angle.

(2) Obtain an inphase null with the Correction RT, and record the "Correction Ratio" for each angle.

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